INFLUENCE OF HVDC COMPOSITE INSULATOR PROFILES ON POLLUTION FLASHOVER PERFORMANCE

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Abstract: In order to optimize HVDC project design, it is very important to study the pollution flashover performance of composite insulators with different profiles under real high altitude conditions. For six types of composite insulators with different profiles, artificial pollution tests at different SDD were carried out in this paper. Meanwhile, the propagation of arc was recorded using a high-speed camera to investigate the flashover process on the surface of the insulators. The experimental results showed that different profiles have great impacts on the flashover voltages. It was observed that the sequence of large shed, middle shed and small shed in one unit has great impacts. The profiles with one large shed and two small sheds in one unit have the largest pollution flashover voltages, because different parameters of the profiles can influence the propagation of arc.

1 INTRODUCTION

In China, at present electricity power supply is vigorously demanded due to the rapid economic development. Large scale electricity transmission over long distances from the country's west part (energy centre) to the east part (industry and load centre) is particularly essential due to China's specific geostrategic deployment. To increase transmission capacity of a single wire and thus to eliminate unnecessary transmission corridors, China has constructed multiple ultra-high voltage transmission lines. For instance, the project of ±800kV DC transmission lines has been built in China, geographically traversing areas of high altitudes that extends approximately 1/3 of the total transmission line length. The altitude of certain regions even achieves 2700m.

Previous studies have revealed that the pollution flashover voltage decreases with the increase of altitude [1-4], and thus regions at high altitude are encountered with much more severe pollution flashover problems. To solve this problem, much effort has been made to increase insulator pollution flashover voltage at high altitude regions. One effective method is to replace procelain and glass insulators with composite insulators. The sheds or the composite insulators are made from hydrophobic silicon rubber, which can largely increase pollution flashover voltage. This has been proved by both operating expertise and laboratory results [5-7].

The pollution flashover property of composite insulators is sensitive to several parameters such as creepage distance, nominal length, type of profile, etc. In prior laboratory experiments and project operations, the deployments of composite insulators are majorly carried out by adjusting the creepage distance because it is believed that pollution flashover voltage increases with larger creepage distance. However, the above consideration is over-simplified in that it overlooks the impact of shed shape on pollution flashover property of composite insulators. For instance, large sheds with small spacings will effectively increase creepage distance, but results in pollution voltage much lower than expected, as has been proved by experimental results. This is because dense arrangement of sheds is prone to cause electric arc bridging, and thus reduces pollution flashover voltage. Therefore, by solely increasing creepage distance with no regard to the shed shape does not necessarily enhance pollution flashover voltage. It is essential to investigate the impact of shed shape on composite insulator pollution flashover voltage.

In order to precisely characterize the impact of shed shape on composite insulator pollution flashover voltage, experiments conducted in real high altitude regions are indispensible. One reason is that the mechanism of composite insulators pollution flashover is so complicated and inter-involving that theoretical or numerical models can hardly give out reliable results. Ever since Obenaus builds the plate model in 1959, despite the fact that much effort has been devoted to modelling pollution flashover process [11-12], the majority of the models presented have been qualitative and unstable. A perceivable reason that model results are less effective is the omitting of a number of potentially interfering factors. The other reason is that, at high altitudes, lower air density is more prone to induce electric arc fluttering and thus to cause the shed shape bridging of composite insulators, which indicates that pollution flashover experience at low altitudes can hardly be directly applied when altitude increases. Both foregoing reasons emphasize the necessity of artificial pollution flashover testing at real high altitudes to obtain experimentally reliable results.

Currently, few laboratories around the world are able to perform full scale flashover testing. The pollution flashover testing performed in laboratories such as STRI in Sweden, Quebec Lab in Canada, EPRI in the United States, NGK in Japan, and CEPRI in China, etc, which are mostly located in the plain areas, are usually performed in imitative high altitude environments. For instance, CEPRI in China imitates high altitude environments by using exhaust fans in a climatic chamber. However, the inherent contradiction of proper pressure control and vapour induced pressure increase limits the precision of this kind of imitation. The credibility of results will further be affected when using the cold fog method because insulators are susceptible to non-uniform wet damping.

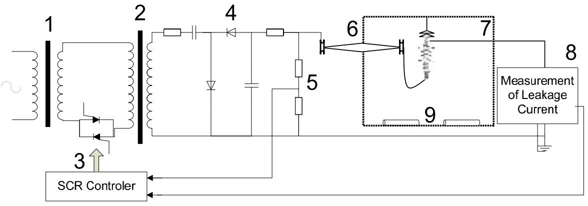
In this paper, the experimental results were obtained at actual altitude of 2100m in Kunming ultra high voltage laboratory. The influence of composite insulators profiles on pollution performance has been investigated. For 6 types composite insulators which have different profiles, artificial pollution flashover testing is conducted by the method of increasing and decreasing voltage. We obtained 50% flashover voltage of all the 6 types of composite insulators under different SDD conditions. Comparison and analysis has been carried out based on the above results, and the optimal shed-type has been sought. This paper also records the flashover process of composite insulators using high speed camera, and further explains the reason for the impact of shed shape on flashover voltage.

2 EXPERIMENTAL SETUP AND MEASUREMENTS

Experiments are all conducted in the National Engineering Laboratory on UHV Technology in Kunming, China (altitude: 2100m).

2.1 Test facilities

The test was supported by a DC power supply which can provide an output of ±1000kV.The system was shown in Figure 1, the appearance was shown in Figure 2. Closed-loop control mode was used to control the output of the power supply. So the ripple factor of the test voltage was less than 3% for a current of 100 mA with a resistive load. The relative voltage drop occurring during individual tests resulting in withstand did not exceed 5%.It met the relevant IEC standard requirement [13].



1- Regulator 2- Testing Transformer 3-SCR 4- Double Voltage Circuit 5- Resistive Voltage Divider 6- Wall Bushing 7-Fog Chamber 8-Measurement of Leakage Current 9-Steam Generator

Figure 1: The experimental system

Figure 2: The appearance of the pollution test hall

The experiments were carried out in the fog chamber. Its parameters and the layout of the fog tubes were shown in Figure 3.The fog was provided by a steam boiler. The steam was sprayed from the four fog tubes which was symmetrical on the floor. The steam input rate was controlled about 0.05 kg/h per cubic metre. Contaminated and dried insulators were vertically hung in the fog chamber.

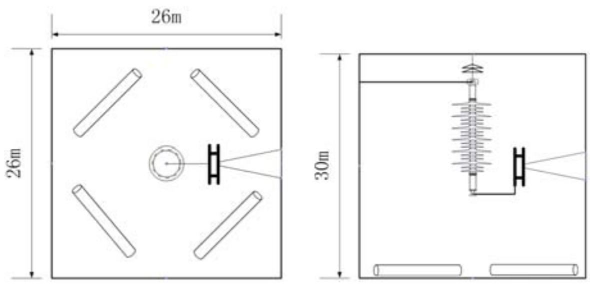
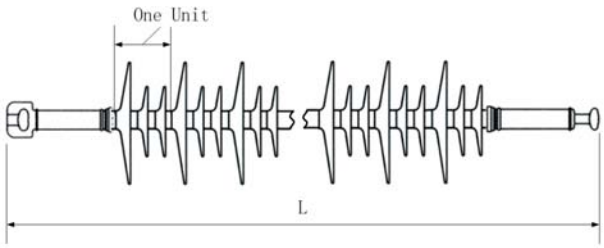


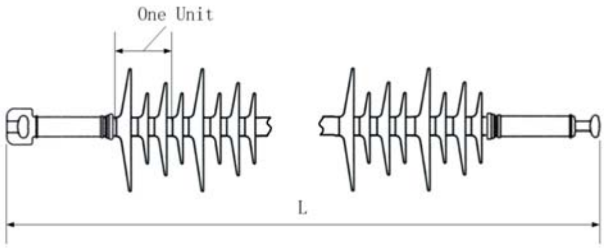
Figure 3: Layout of the fog chamber

2.2 Test specimens

Six types of composite insulator which had the same nominal length and creepage distance was tested in this paper. There were three types of shed in this paper. They had different size, one was large shed, one was middle shed, and the other was small shed. Normal composite insulator was consisted by some units which were the same. One unit conclude some large shed, middle shed and small shed in order. According to different unit, the six kinds of insulators was divided into three kinds which were style A, style B, style C. Style A has one large shed, two small sheds. Style B has one large shed, one middle shed and two small sheds. Style C has one large shed, one middle shed, four small sheds, as shown in Figure 4.D_1 was the diameter of the large shed, D_2 was the diameter of the middle shed and D_3 was the diameter of the small shed, while L was the nominal length of the insulators.



A



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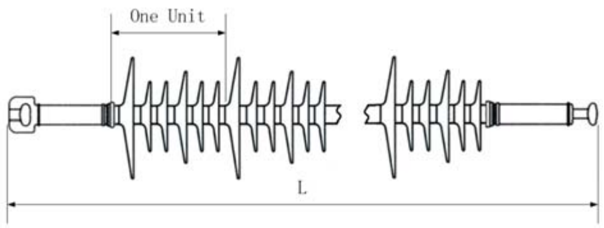


C

Figurer 4: Three styles of composite insulator

The six types of insulators were numbered 1#-6#, and their parameters were shown in Table 2.

Table 2. Parameters of composite insulators

No.	Shed style	D_1 /mm	D_2 /mm	D_3 /mm	L /m	Creepage distance /m
1#	A	200	None	140	10.2	36.27
2#	A	226	None	154	10.2	38.25
3#	B	226	176	130	10.2	36.10
4#	B	205	165	125	10.2	36.00
5#	C	227	187	137	10.2	38.25
6#	C	218	166	121	10.2	38.00

2.3 Test procedure

The solid layer method was used. Because different types of composite insulator have different formula, the hydrophobicity of them was different. When they were stayed the same time, they had different hydrophobicity on the surface. Then the experiment result would be influenced not only by the profiles but also by the hydrophilicity. However, only the pollution flashover influenced by the profiles was concerned in this paper, we must carry out this experiment when the surface of the insulators was hydrophily. It means that we finish contaminating the insulator, and then conduct the experiment after the surface was dry immediately. The test flow chart was shown in Figure 5.

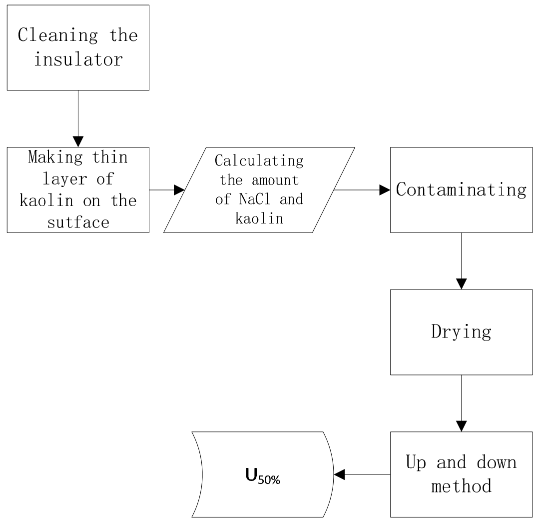


Figure 5: Test flow chart

1) Pretreatment

First, clean the surface of the insulators. Then take them on the shelves waiting for natural drying.

2) Contaminating operation

Composite insulators had hydrophobicity, so it was hard to contaminate them. Therefore we take a thin layer of Kaolin on the surface of them which can destroy the hydrophobicity of the surface. Because the layer was so thin that, the NSDD was impacted little.

A suitable amount of salt (NaCI) of commercial purity, kaolin and water were made into suspension. Then the suspension was brushed on the surface of the insulator. The amount of them was calculated by the SDD, NSDD and the area of the insulator.

3) Drying

The layer shall be left to dry prior to the submission of the insulator to the test. After about 2.5 hour, when the surface was dry, the experiment was carried out immediately.The hydrophobicity of the contamination layer being at a level of HC7.

4) Test

The 50% flashover voltage U50% was determined by the Up and Down method. It had been confirmed than in the case of negative polarity, the lower flashover would be taken, so the negative polarity test were chosen.

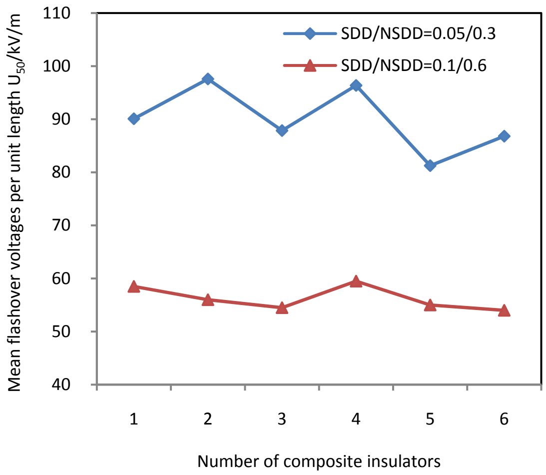
3 EXPERIMENT RESULTS

The experiment in this paper was carried out in the same environmental condition which was shown in Table 3.

Table 3 Environmental Condition

	Temperature (℃)	Humidity (%)	Altitude (m)
Value	16-25	55-65	2100

For every kind of composite insulators, experiment under two types of SDD, one was 0.05g/cm^2 and the other was 0.1g/cm^2, were carried out. The ratio between NSDD and SDD was 6 which was commonly used in China. The result was shown in Figure 6.



Figurer 6: Mean flashover voltages per unit length plotted against different number of composite insulators

When SDD was 0.05mg/cm^2 and NSDD was 0.3mg/cm^2, the insulator 2# of style A had the highest pollution flashover and the insulator 5# of style C had the lowest pollution flashover.

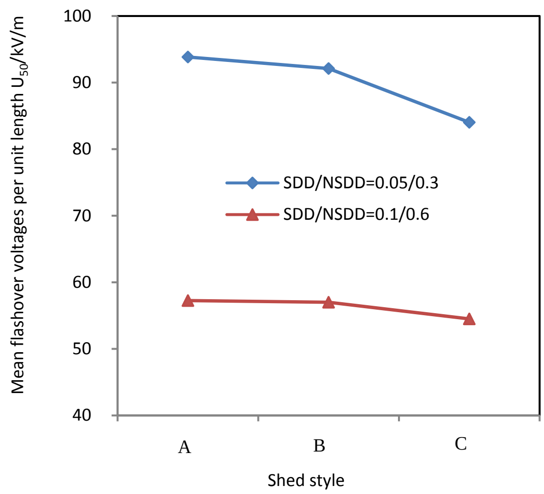
When SDD was 0.1mg/cm^2 and NSDD was 0.6mg/cm^2, the insulator 4# of style B had the highest pollution flashover and the insulator 6# of style C had the lowest pollution flashover.

4 DISCUSSION

4.1 Influence of the profile on the pollution flashover voltages

Experimental results show that when SDD=0.05mg/cm^2, maximum pollution flashover voltage of insulator 2# exceeds minimum of insulator 5# by 20.1%; when SDD=0.1mg/cm^2, maximum pollution flashover voltage of 4# exceeds minimum of 10# by 10.2%.The result showed that the profiles of the composite insulator had an important bearing on its pollution performance and the optimizing of the profile was of great significant

The flashover voltage of style A was the average of insulator 1# and 2# and the flashover voltage of style B was average of insulator 3# and 4# while the flashover voltage of style C was average of insulator 5# and 6#.The flashover voltages of this three styles were compared to research the influence of different sequence of large shed, middle shed and small shed on the pollution performance.



Figurer 7:. Influence of different profile on the pollution flashover voltages

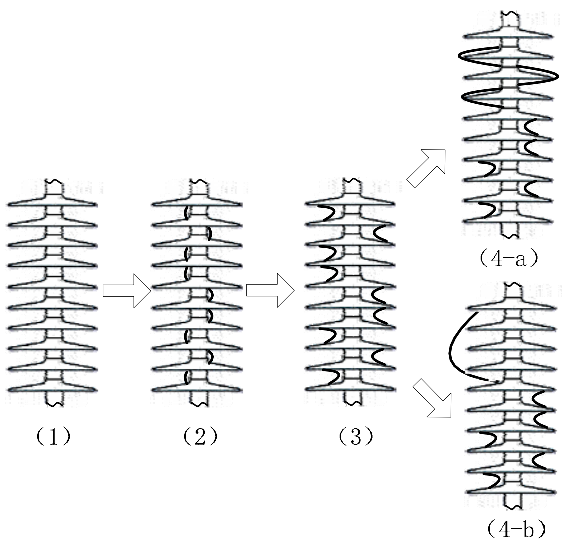
As shown in Figure 7, style A had the most significant advantage while style C had lowest pollution flashover voltage under two different SDD. The pollution flashover voltage of style A was slightly higher than that of style B. So at high altitudes style C would be abandoned. From the result of this paper, style A would be recommended. And the other parameters of style A, such as diameter of the shed, repeat distance, leakage distance needed further investigation.

4.2 Analysis the reason of the influence of the profile on the pollution flashover

It is confirmed through service experiences and laboratory tests that pollution flashover voltage will be significantly reduced at high altitudes because of lower atmospheric pressure. The arc at high altitudes was easy to levitation which would lead to bridge the sheds of the insulator. Reasonable shed design can restrain the levitation of arc and improve the pollution flashover.

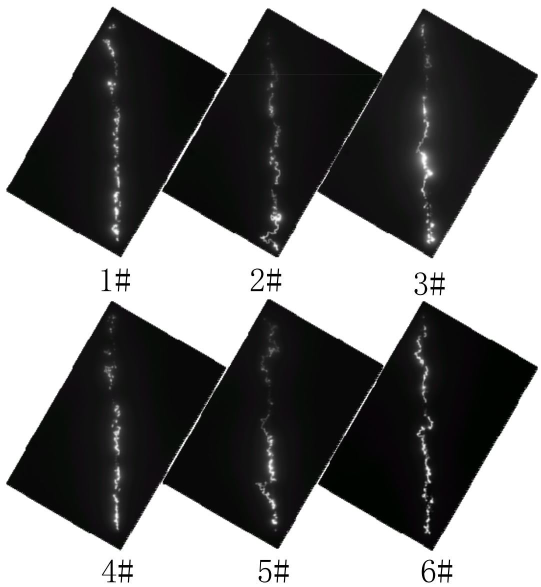
The pollution flashover of insulators contains four processes: pollution deposit, wetting, dry band arcing, flashover.

For insulator stings, the process of the flashover was shown in Figure 9.Fitstly, when the voltage we made on the insulator, there was leakage current flowing on the surface of the insulator. Secondly, because the rod had smaller diameter, it get more current density and became hotter. Then the heat made the dry band formulation. After that the local arcs appeared. These local arcs did not all occur on the same side and there was no obvious regularity. Thirdly, as the contamination layer was damped further, dry bands appeared to spread out onto the sheds. Finally if the shed was designed well, the arc would propagate on the surface of the insulator which was shows in picture 4-a of Figure 8. However, if the shed was not designed well these dry bands were bridged by the arcs. In due course these arcs joined together to bridge from major shed to major shed across a minor shed, then spreading out across a few sheds, which just like picture 4-b shown in Figure 8.



Figurer 8: Arc propagation on composite insulator

When SDD was 0.1 mg/cm^2 and NSDD was 0.6 mg/cm^2, the high-speed camera was used to record the propagation of arc. The results were shown in Figure 9. The insulator was so long that the diagonal of the lens of the camera had to be used. When the flashover happened, the propagation of the arc was different from each other. The arc of insulators 5# and 6# levitated from the surface, and then bridge the sheds of them. Therefore They have lower flashover voltages.. Therefore they have lower flashover voltages. The arc of the insulators named 1# and 4# propagated nearly on the surface. So they had higher flashover voltages.



Figurer 9: The process of flashover of the composite insulator in SDD=0.1 g/cm^2

Insulator 1# and Insulator 4# had higher the distance between the edges of their big shed and small shed was larger. From the experiment result in this paper, this style of shed could improve the pollution performance of the composite insulator. Insulator 5# and Insulator 6# wanted to get more creep distance, so the sheds of them were designed too dense. But this style was easy for the arc to bridge the sheds. Therefore the pollution flashover got lower instead.

5 CONCLUSION

Shed shape of composite insulators exerts conspicuous influence on pollution flashover voltage of composite insulators. In this paper, 6 types of insulators with different profiles are investigated. Experimental results show that when SDD=0.05mg/cm^2, maximum pollution flashover voltage exceeds minimum by 20.1%; when SDD=0.1mg/cm^2, maximum pollution flashover voltage exceeds minimum by 10.2%.

By analysing the above experimental results, we conclude that the profile with one large shed and two small shed per unit, exhibits highest pollution flashover voltage. More detailed parameters of this type of composite insulator is worth further investigation.

It is deduced that different profile exerts conspicuous influence on pollution flashover voltage because it inhibits bridging of arc. By recording the flashover process of different composite insulators using high speed camera, it is concluded that composite insulators with proper shed shape can hardly been bridged by arc.

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